VIII.B.3 Hydrogen Power Park Business Opportunities Concept Project

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Boyle & Associates, Emmaus, PA
Collier Technologies, Reno, NV
Energy CS, Monrovia, CA
ETEC, Phoenix, AZ
Delta Diversified Electric, Phoenix AZ
Kinetics, Phoenix, AZ
Simplex-Grinnell, Phoenix, AZ
University of Colorado, Boulder, CO

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Projected End Date: December 31, 2006

Objectives

- Develop models for off-peak and grid connected power park systems.
- Evaluate the performance of the model power parks through testing of components.
- Identify model power park economic parameters.
- Develop operational envelopes for optimized models.
- Identify the customer value proposition.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- C. Hydrogen Refueling Infrastructure
- D. Maintenance and Training Facilities

- E. Codes and Standards
- H. Hydrogen from Renewable Resources
- I. Hydrogen and Electricity Co-Production

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE technology validation milestones from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- *Milestone19: Complete Power Park Demonstrations and Make Recommendations for Business Case Economics.* We are operating all of the Power Park elements at the Pilot Park in downtown Phoenix. Evaluating the Hydrogen Park issues such as fire department and building official interpretation of existing codes and standards, safety, efficiency, reliability, public acceptance, system integration, emissions, and cost create a database. Using this data, value propositions for particular business applications will be modeled, and recommendations for potential applications made to the DOE.

Approach

- Identify Power Park conceptual models based upon regulations, costs, and benefits.
- Validate model performance by testing of components at the Pilot Power Park.
- Analyze the business case for each model using actual performance and costs.
- Value-engineer each Power Park model to identify opportunities to improve economics.
- Identify opportunities to integrate the Power Park with utility system operation.
- Identify the customer value proposition.

Accomplishments

- Pilot Hydrogen Park permitted by the City of Phoenix Fire Department for motor vehicle fueling and high pressure gasses (equipment located inside an historic building, in the historic district of downtown Phoenix).
- Compact hydrogen storage/compression module approved by the Phoenix Fire Department for installation at conventional gasoline stations (very high level of safety).
- Three years of operation at the Pilot Park without any safety events or near misses.
- 6,588 Kg of hydrogen produced from a membrane electrolyzer for vehicle fueling and electricity generation.
- More than 4,000 vehicle credit card fueling events without any incidents. The park is open to the public for vehicle refueling, see Figure 1.
- 35 Mwhrs of electricity produced at the Pilot Park.
- 8,192 kWhrs of electricity produced over 4,468 operational hours by PEM fuel cells operating at a net DC electrical efficiency of 46%.
- Electrolyzer operational availability is 99% after 39 months, producing 99.9997% pure hydrogen (purity certification by Air Liquide).
- Performance testing of the following equipment:
  - 5 kw fuel cell, net DC efficiency 46%.
  - Hogan 300 electrolyzer net efficiency of 41% with a power factor of .59.
  - 8.3 L 120 kw Cummins-Onan genset 28% efficiency (100% hydrogen, 70/30 CHyNG blend)

   - 10 kw Alterdyne Genset with Lister Petter motor 28% efficiency (100% hydrogen).
   - 5.4 L V8 (low and high boost supercharging) 40% peak efficiency (100% hydrogen).
- Pilot Hydrogen Park monitoring and control system installed and operating that provides a continuous analysis of reliability and efficiency of components and integrated systems (internet accessible - about 700 hits per month).
- Vehicle emission testing using the Federal Test Procedure (FTP) driving cycle with vehicles using 100% hydrogen and 70/30% & 85/15% hydrogen enriched natural gas.
- The cost of producing hydrogen (electrolyzer) from photovoltaic energy has been modeled using a wide variety of equipment and technology.
- The cost of producing hydrogen (electrolyzer) using Arizona Public Service (APS) grid electricity with commercial rates has been modeled.
- The cost of producing hydrogen (electrolyzer) using the APS marginal cost of fuel has been modeled.

Figure 1. APS Pilot Hydrogen Park in Downtown Phoenix (The park is open to the public for motor vehicle fueling.)

Future Directions

- Evaluate the cost of hydrogen produced from wind energy.
- Evaluate the cost of hydrogen produced from biomass and biogas.
- Performance test new electrolysis equipment.
- Performance test new fuel cell.
- Integrate test result with Power Park Models.
- Construct the mobile distributed energy model.
- Identify hydrogen park customer value propositions.
- Identify utility operations envelope with power park.
- Finalize Model Park designs with economics.

Introduction

A Power Park is a potential pathway for hydrogen implementation into society. In addition to producing hydrogen, the park should incorporate renewable energy, fuel motor vehicles, and generate electricity. The Arizona Public Service (APS) project focuses on "real-world" equipment and performance by integrating components into the APS Pilot Hydrogen Park. The performance of these components can then be monitored over time to establish their durability and performance. The Pilot facilitates communication with local building code authorities on code issues. The Pilot was permitted by the Phoenix Fire Department and continues to be reviewed for every modification. With a perfect safety record, more than 4,000 credit card fueling events and 6,588 kg of hydrogen produced and consumed at the Pilot, a good level of creditability has been established with the Phoenix code authorities.

A commercial Power Park must create a value proposition for its owners or customers. Precursors to the value propositions are safety, reliability, and product quality. Typically, the value proposition implies equivalent or superior performance at a lower cost. Can a hydrogen power park offer such an advantage over the status quo in certain circumstances? This project goal is to identify a few hydrogen park models that create a value proposition, based upon real world economics, performance, and realities.

Approach

Four Power Park models will be identified which offer high potential to provide a value proportion for its users. These models will be based upon assumptions of regulations, costs, performance, and benefits at the beginning of the project. Components, equipment, and processes needed for a power park will be tested. This will include performance testing which can validate manufacturers' claims of efficiency and durability testing which will validate manufacturers' claims of useful life and anticipated operating/maintenance costs. In addition to real world performance results, the safety of components and systems can be determined. Testing will occur at the APS Hydrogen Park, which permits operation of a fully integrated system and commercial vehicle refueling.

Economic analysis will be based upon the testing performed at the Pilot Park and existing APS operations. Renewable energy data will be based upon the renewable energy systems installed by APS in Arizona. APS commercial electric rates will provide the cost basis for grid electricity. The APS generation mix will provide the basis for emissions from grid operations and the marginal cost of fuels available to produce energy. Combining all of the performance and economic data will be focused on the original hydrogen power park models to identify opportunities for cost savings, enhancement, and potential value propositions. As with normal energy operations, any value proposition implies that safety, reliability, and quality expectations are met.

Results

The Pilot Hydrogen Park control and monitoring system became operational in August 2004. The completion of this system permitted continuous performance monitoring of the hydrogen production, compression, storage, and dispensing of hydrogen and hydrogen enriched natural gas fuel. A feature of this system is its internet accessibility. The Future Fuel site is accessible under www.aps.com, *My Community,* see Figure 2. Users of the site can view

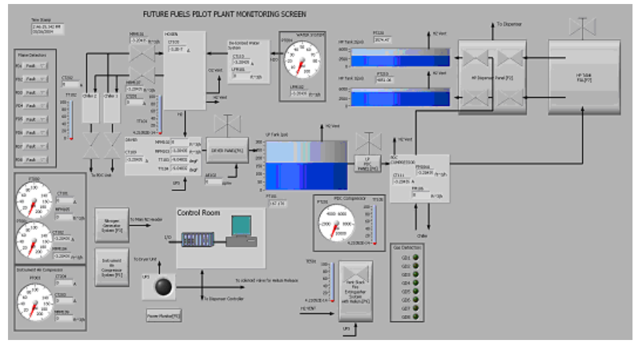

Figure 2. Control Panel for APS Pilot Hydrogen Park (Internet accessible: www.aps.com/ *My Community/Future Fuels)*

the Pilot Park's control panel in real time and view efficiency and cost performance of the various components within the Park. Additionally, the status of all of the Pilot Park's many systems is displayed.

Safety, reliability, and quality performance has been good for the equipment and components tested. There have been no accidents, near misses, or damage during the 3 years of operation, 4,000 motor vehicle fueling events (credit card), 35 MWh of electric production with fuel cells, internal combustion engine (ICE) gensets, and photovoltaic panels. The membrane stack electrolyzer had an availability of 99+% over 8,573 hours of operation during 28,440 calendar hours. The Proton Hogen 300 electrolyzer has produced 6,588 kg of hydrogen. The hydrogen compressor (triple diaphragm) had an availability of 99+% with the outage coming from diaphragm replacement that occurs annually. The reliability of the fuel cells tested has been mixed, but recent durability runs on the Plug Power 5 kW unit have been very good with two shutdowns over five months. The quality of the hydrogen produced has consistently been third-party tested and determined to be 99.9997% pure. Motor vehicle fueling under the control of an advanced dispenser has been performed safely and to the satisfaction of Nissan's advanced fuel vehicle test team. Accuracy of blended fuel mixtures has been consistent with the advanced dispenser. The general public's (non-APS) acceptance of the motor vehicle fueling experience has been very good with some of the station customers modifying their engines to accept more hydrogen blend.

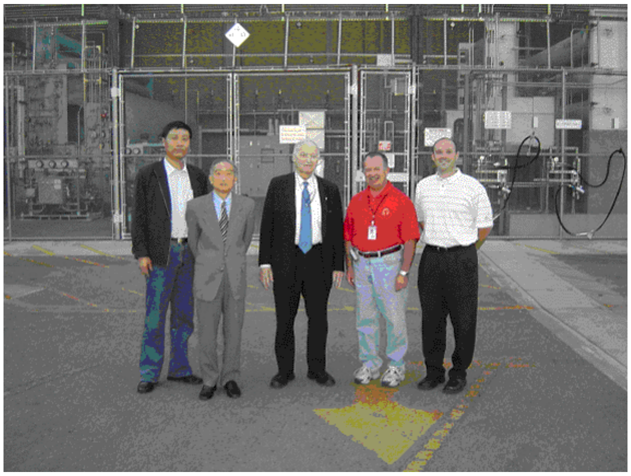

Figure 3. Tour of the APS Power Park, December 2004 *From left to right:* Peng Oiming (Director, Science & Technology at China Geological Survey), Professor Tang Keding (Chief Energy Advisor to Chinese Government), Maurice Strong (Under Secretary General of the United Nations), Ray Hobbs (APS, Future Fuels Program) and Mark Riley (Clean Energy).

The Hogen 300 electrolyzer efficiency was measured to be 41.3% (LHV) which compares unfavorably to the DOE target of 68% for electrolysis efficiency. This efficiency precipitates a motor vehicle fuel production efficiency (compression and dryer) of 39.3% which compares unfavorably to the DOE target efficiency of 64%. Using the APS electric rate (E35) for a large electric customer using off-peak energy, the cost of energy to make a kilogram of hydrogen is $1.70 which compares favorably to the DOE target of $1.80/kg. Plug Power fuel cell efficiency was measured to be a net 46% efficient which compares favorably to the DOE target of 32% efficient. Peak ICE genset using hydrogen and blends of hydrogen natural gas was measured to be 28% with unmodified engines, which compares unfavorably to the DOE target of 32%. Peak engine efficiency using modified ICE automotive engines was 40%, which compares favorably to the DOE target of 32%. See Tables 1-3.

Conclusions

- Hydrogen can be safety dispensed as a motor vehicle fuel.
- Hydrogen can be safely handled at 6,000 psi.
- Hydrogen production, compression, and storage equipment and their appurtenances can provide high reliability and safety.
- Hydrogen can be used in internal combustion engine as a fuel or fuel additive.
- NOx emissions can be very low from hydrogen ICEs when lean burn is implemented.
- Power from hydrogen ICEs requires very high mass air flow to provide sufficient air to support lean burn for low emissions, while supporting enough combustion to produce high power.
- Hydrogen can be produced from renewable resources, but at a higher cost than traditional sources.

Special Recognitions & Awards/Patents Issued

1. Recognition by U.S. DOE Clean Cities Program at annual conference, May 2004, Ft. Lauderdale, FL.
2. Recognition by Valley of the Sun Clean Cities Coalition at "Arizona's Road to Clean Air and Energy Independence" Legislative Event, February 2005, Phoenix, AZ.

FY 2005 Publications/Presentations

1. Presentation to the Aspen Clean Energy Roundtable, June 2005, Aspen, CO.
2. Presentation at 2005 DOE Hydrogen Program Review, May 2005, Crystal City, VA.
3. Presentation at U.S. DOE Solar Hydrogen Workshop, November 2004, Adelphi, MD.
4. Hosted a Department of Energy Thermochemical H2 Production Meeting, November 18-19, 2004, Phoenix, AZ.
5. Tour/presentation to Valley Leadership, November 2004, Phoenix, AZ.
6. Presentation to SAE Regional Meeting, October 2004, Phoenix, AZ.
7. Presentation to NREL, October 2004, Golden, CO.
8. Article published in National Hydrogen Association Newsletter, August 2004.
9. Presentation at Southwest Renewable Energy Fair, August 2004, Flagstaff, AZ.
10. "Making the Transition to the Hydrogen Economy" Presentation at the ASES Solar Conference, July 2004, Portland, OR.

Table 1. Cost of Hydrogen From Solar Energy with Electrolysis, Using APS STAR Data, Using Both Pilot Hydrogen Park Existing Efficiency and DOE Target Efficiency

Solar Type	Cost $/watt	Cost $/kwh	Energy kWwh/ kW-yr	Cost Kwh/$	Cost $/kwh	Cost H2 $/Kg @ 41.27% Eff.	Cost H2 $/Kg @ 68% Efficiency
PV Fixed Horizontal	5.25	0.01	1,250	4.75	0.220	$17.80	$10.81
PV Fixed Latitude	5.25	0.01	1,630	6.20	0.171	$13.84	$8.40
PV Tracking Horizontal	5.50	0.01	2,350	8.55	0.127	$10.28	$6.24
PV Tracking Latitude	6.50	0.01	2,450	8.25	0.131	$10.60	$6.43
PV High-Concentration	6.00	0.01	2,030	6.75	0.158	$12.79	$7.76
PV High-Concentration (Future)	3.00	0.01	2,400	16.00	0.0725	$5.87	$3.56
Organic Rankine Cycle Trough	4.00	0.03	2,000	10.00	0.130	$10.52	$6.39
Dish Turbine	2.50	0.03	2,400	19.20	0.082	$6.64	$4.03

Table 2. Cost Comparisons of Energy, Fuels, and Hydrogen

	$/kwh	H2 Conversion Efficiency %	Conversion Process	H2 Energy Cost $/Kg
Energy				
APS X-Large Commercial	0.02792	68	Electrolysis	$1.37
APS Residential Rate	0.04299	68	Electrolysis	$2.11
Renewable Energy				
Wind - Best Case	0.04	68	Electrolysis	$1.96
Solar PV - Best Case	0.127	68	Electrolysis	$6.24
Solar Thermal - Best Case	NA	68	Cracking	
Biomass	0.06 – 0.12	68	Electrolysis	$2.95
Biogas - Municipal	0.05 – 0.08	68	Electrolysis	$2.46
Biogas - Agriculture	0.06 – 0.10	68	Electrolysis	$2.95
Commercial Fuels				
Uranium (PVNGS)	0.004	68	Electrolysis	$0.20
4C Coal - $20.430/ton	0.012	65	POX	$0.62
Spot Market Gas $7.16 MMBtu	0.0244	80	Reformer	$1.02
CNG (Street) $9.318 MMBtu	0.0318	80	Reformer	$1.33
Residential Gas $13.469 MMBtu	0.0459	80	Reformer	$1.92
Gasoline – Unleaded $2.25/gallon	0.0674			
Diesel - $2.37/gallon	0.0709			
Gasoline – Premium $2.50/gallon	0.0748			

Table 3. Cost of Hydrogen from Electrolysis Using Off-Peak Electricity With Existing APS Electric Rate Classes (On-Peak 9:00 a.m.- 9:00 p.m. Monday - Friday)

ELECTRIC RATE CLASS	Summer: May – October			Winter: November – April			Demand	Demand
	On Peak	Off Peak	Off Peak H2 Energy Cost*	On Peak	Off Peak	Off Peak H2 Energy Cost*	Summer	Winter
	$/kwh	$/kwh	$/kg	$/kwh	$/kwh	$/kg	$/kw	$/kw
Residential	0.13310	0.04299	$2.11	0.10918	0.04167	$2.05		
Commercial Small	0.09610	0.04429	$2.18	0.08610	0.03429	$1.68		
Commercial Med	0.07938	0.04175	$2.05	0.06945	0.03182	$1.56	$11.334	$11.334
Commercial Large	0.05283	0.03797	$1.86	0.04723	0.03393	$1.67	$9.390	$8.510
Commercial X-Large	0.03529	0.02792	$1.37	0.03529	0.02792	$1.37	$12.209	$12.209

* Gasoline Energy (LHV 114,000 BTU/gallon) is equivalent to 33.4 kWhrs. Rates effective April 1, 2005. CostBased Upon DOE Target Electrolysis Efficiency of 68%